Winning the 6th High Magnetic Field Forum Frontier Award for Young Researcher

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At the Annual Meeting of the High Magnetic Field Forum held on December 18th 2024, I was greatly honored to receive the 6th Frontier Award for Young Researcher. This award was established to encourage and support promising young scientists in the field of high magnetic fields, particularly those who demonstrate originality and innovation in their research. I would like to sincerely thank the selection committee for this recognition.

The award-winning research, titled "*Hidden fine structure in the thermodynamic probing of Landau quantization at high magnetic field*" is part of our recent series of studies that revealed a previously unrecognized double-peak structure in the quantum oscillations of specific heat. These findings open new possibilities for thermodynamic investigations of quantum materials under extreme conditions.

Since my PhD studies, I have been exploring Landau quantization through various physical quantities under high magnetic fields. While quantum oscillations are typically investigated via resistivity (Shubnikov–de Haas), magnetization (de Haas–van Alphen) or cyclotron resonance (optical transitions between Landau levels), thermodynamic probes—such as specific heat and the magnetocaloric effect—have rarely been employed, particularly in extreme-field regimes. This is largely due to the experimental challenges involved, including low signal-to-noise ratios and the technical complexity of performing such measurements in high magnetic fields. Overcoming these obstacles required the development of high-resolution calorimetry capable of operating under high magnetic field up to 50 T. This capability ultimately enabled the discovery of previously hidden thermodynamic features near the quantum limit.

In this research, I applied high-resolution calorimetry up to 50 T to two very different quantum materials: the well-known semimetal graphite, and the topological Kondo insulator YbB_{12}. Remarkably, in both systems, I observed a previously hidden double-peak structure in the vicinity of the quantum limit. In graphite, these double peaks could not be explained by the standard Lifshitz-Kosevich theory. Detailed modeling revealed that they originate from the Fermi–Dirac distribution function itself, offering a rare opportunity to directly determine the effective mass and Landé g-factor independently of traditional methods [1]. In YbB_{12}, which lacks of free electrons, the presence of similar double peaks suggested the emergence of charge-neutral fermions—exotic quasiparticles that may be linked to composite excitons or Majorana fermions [2]. The convergence of these features in two drastically different systems points to a deeper, universal aspect of fermionic quasiparticle when entropy is probed directly.

This work also provides broader thermodynamic insights into other quantum materials, with implications extending across various areas of condensed matter physics. For example, recent specific heat measurements in Kagome antiferromagnets revealed similar double-peak structures, which served as a thermodynamic fingerprint of fermionic quasiparticles, supporting the presence of spinon-based charge-neutral excitations [3]. Moreover, while logarithmic temperature dependence in specific heat has long been regarded as a hallmark of non-Fermi liquids, our study demonstrated that such behavior can also arise from conventional fermionic excitations. This finding offers a clarified perspective on the physical origin of this widely discussed phenomenon.

Behind this progress lies a quiet but meaningful story. The double-peak structure was first observed in YbB_{12}, and for a long time, we believed it to be a unique feature of topological Kondo insulators. We spent considerable time and effort trying to understand it within that framework—but to no avail. The turning point came unexpectedly—while revisiting an old dataset of graphite collected nearly six years earlier, we noticed a remarkably similar double-peak structure that had gone unnoticed at the time. This realization made it clear that the phenomenon was not unique to topological Kondo insulators, and it prompted us to reframe the question through a broader conceptual lens. The story of finding the answer in six-year-old forgotten data was a vivid reminder that, scientific breakthroughs often arise from serendipity rather than design—making long-term accumulation and sustained curiosity all the more essential.

At the end of this report, I am especially grateful to Prof. Yoshimitsu Kohama (University of Tokyo) and Prof. Duncan K. Maude (CNRS, France) for their mentorship, encouragement, and invaluable guidance throughout this journey. Their support has played a crucial role in helping me pursue long-term research on high-field thermodynamics with confidence and clarity. I also thank Prof. Christophe Marcenat and Prof. Thierry Klien (CEA, France) for international collaboration and fruitful discussions. This work would not have been possible without the intellectually open and supportive environment provided by the International MegaGauss Science Laboratory (IMGSL) at ISSP, the University of Tokyo, which has allowed me to pursue long-term, curiosity-driven research with great freedom. Receiving this award encourages me to embark on the next stage of research with renewed patience and curiosity—pushing the frontiers of high-field science further.

Reference:

[1] Z. Yang et al., *Nature Communications* **14**, 7006 (2023)

[2] Z. Yang et al., *Nature Communications* **15**, 7801 (2024)

[3] G. Zheng et al., arXiv preprint arXiv:2409.05600 (2024)

Figure 1. Award ceremony for Dr. Yang Zhuo (right) with Prof. Yasuo Narumi (left).